

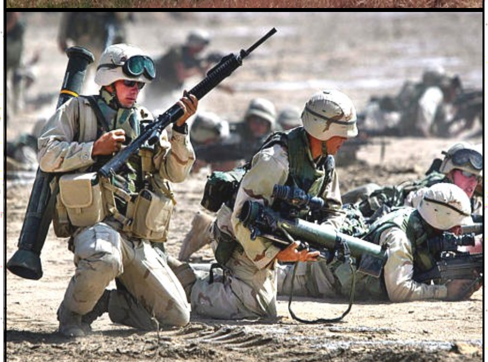
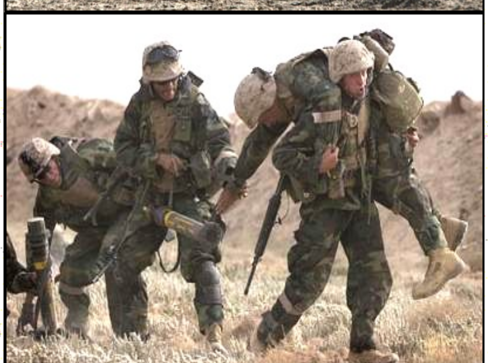


Disaster Medicine: Using Modeling and Simulation to Determine Medical Requirements for Responding to Natural and Man-made Disasters

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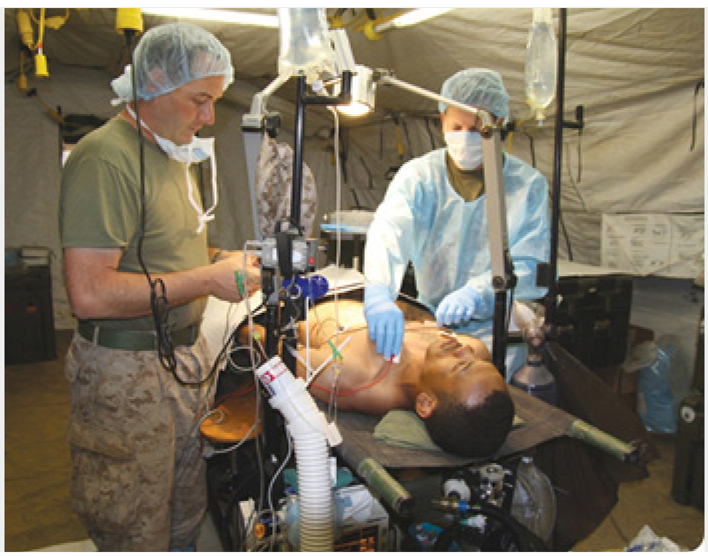

Navy medical personnel prepare a simulated wounded Marine for surgery in the Forward Resuscitative Surgical System, a far-forward surgical unit carried in three Humvees and developed with the aid of Navy medical modeling and simulation. Photo Credit: USMC photo

Abstract

It has been suggested that civilian emergency managers should leverage the knowledge and expertise of military medical planners when preparing for medical disaster response. Like their civilian counterparts, military medical planners are faced with personnel shortages and restricted resources. Military medicine, therefore, uses medical modeling and simulation (M&S) to take the guesswork out of developing new field medical capabilities or to preplan deployments for any number of emergency contingencies in austere environments. Civilian disaster medical planners could learn from military medicine's M&S efforts. To take full advantage of medical M&S, however, civilian researchers must make a concerted, long-term effort to collect patient care data during disaster responses. The collected data must include the type and number of injuries and illnesses seen by responders, including anatomical locations when

appropriate, and the treatment provided. Once collected, the data must be centralized so it can be coded and made available to medical analysts.

The past decade is likely to be remembered for its disasters. The first 10 years of the 21st century saw a tragic series of devastating man-made and natural disasters: major terror attacks in the United States, England, India, and Spain; the wrath of hurricanes Katrina and Rita; and the sweeping destruction of the 2004 Indian Ocean earthquake and tsunami. Natural or man-made, these disasters strained the capabilities of local medical facilities and medical-response units to treat the resulting injured and sick. During this same period, U.S. military forces fought wars in Iraq and Afghanistan, stressing the capabilities of military medical providers. In the latter case, however, the evolution of medical modeling and simulation (M&S) helped ease the guesswork previously used to determine what type of treatment facilities were required and how much equipment and consumable supplies they should carry. Unfortunately, medical M&S for civilian disaster response has not kept pace.

Despite increased awareness of the need for improved medical response to disasters, little has been done to improve the way local communities, states, and the nation as a whole prepare for major mass-casualty events. Despite millions of dollars in federal homeland security funding following the terrorist attacks on September 11, 2001, there was no systematic review of what was needed for a medical response to a major disaster. Much of the funding requirements emphasized responding to chemical, biological, radiological, or nuclear events, with little regard given to the most likely mass casualty incidents, such as conventional terrorist bombings and natural disasters. As a result, little progress toward improved disaster response readiness was achieved, and much of what was purchased with that funding was useless (Kimery, May 13, 2008).

As early as 2005, the year of Hurricane Katrina, federal emergency preparedness money began drying up, falling as much as 25% by 2009 (Closing the Seams, 2007; Ferenc, 2010). In 2010, a large-scale federal and local disaster exercise in Las Vegas was canceled due to its high cost, and additional exercises may be canceled as well (Hsu, 2010). At the same time, America's network of trauma centers and hospital emergency rooms (ERs)—the frontline "receivers" in the event of a terrorist attack or natural disaster—are in crisis. In 2004, the National Foundation for Trauma Care predicted that 10%–20% of the nation's trauma centers would close within 3 years (U.S. Trauma Center Crisis, 2004). Between 2006 and 2008, five trauma centers did close, and another five downgraded their level of care. More than 12% of the nation's hospitals closed their ERs between 1994 and 2004; many hospitals closed down entirely. In addition, there is a shortage of health care providers, especially trauma and critical care specialists (Kimery, May 20, 2008, 2010; Wilper et al., 2008).

Unprepared for the "Predictable Surprise"

Dwindling funding and emergency medical resources are leaving the United States dangerously unprepared for another disaster with mass casualties. A report issued by the House Committee on Oversight and Government Reform maintains the country is unprepared to deal with the "predictable surprise," which the committee described as a terrorist bombing like the one that struck commuter trains in Madrid, Spain, on March 11, 2004. On March 25, 2008, the committee conducted a survey of 41 Level 1 trauma centers in seven major U.S. cities. None of the cities—New York, Los Angeles, Chicago, Houston, Denver, Minneapolis, and Washington, D.C.—had the capacity to treat the more than 2,000 casualties created by the Madrid blasts (Hospital Emergency Surge Capacity, 2008).

Military medical providers, like their civilian counterparts, have been stretched thin by two wars and an ongoing shortage of medical personnel (Gahol, 2005; Schrader, 2004). Furthermore, space limitations on cargo ships and aircraft mean battlefield medical treatment facilities (MTFs) must maintain a relatively small logistical footprint while still providing advanced medical care to hundreds of injured and sick service men and women. Military medical planners frequently use medical M&S to meet both the restrictions and the requirements of their military medical mission. Because military operations today span a wide range of scenarios (e.g., large-scale warfare, counterterrorism and antipiracy operations, peacekeeping, humanitarian, and disaster response), medical M&S efforts provide an all-hazards approach to planning. Civilian medical disaster M&S tools do exist. A study described in the August 2009 issue of Medical Decision Making reviewed 55 medical models and M&S programs. For the most part, these were special-purpose models focusing on specific disease outbreaks or pandemics. Only a few addressed natural disasters, and even fewer focused on man-made disasters. “Despite the frequency and potentially catastrophic health consequences of natural disasters [...] remarkably few published models have focused on the public health and medical responses to such events,” the study reported. It also found that “relatively few models have addressed response to man-made disasters such as conventional warfare, radiologic and chemical accidents, acts of terrorism, and large-scale industrial accidents” (Brandeau, McCoy, Hupert, Holty, & Bravata, 2009). Optimize Patient Care

Medical M&S can help medical disaster planners prepare their communities for a variety of natural and man-made disasters at relatively low cost. For instance, M&S can test a variety of configurations for a proposed disaster MTF to find the best composition of equipment and personnel before committing to the cost of buying matériel or hiring people. The same process can be used to develop strategies to task-organize that response unit for different disaster scenarios (earthquake, tornado, hurricane, flood). Patient flow and treatment can be optimized by M&S analysis for a single hospital or an entire community’s health care network. None of this can be done, however, without the appropriate empirical data. Unfortunately, little of that is available. Much of what we think we know about disaster medicine is based on conjecture or anecdotal information. The unexpected nature of disasters is at least partly responsible for this; once in the midst of treating disaster victims, providers give little thought to data collection (Dominici, Levy, & Louis, 2005; Heide, 2006; Quick & Hogan, 2002). A decade ago, military medical M&S suffered from this same lack of data. With the invasions of Afghanistan and Iraq, a concerted, joint-forces effort was launched by military medicine to capture injury, illness, and treatment data from the battlefield. For example, the Naval Health Research Center (NHRC) maintains the Navy-Marine Corps Combat Trauma Registry Expeditionary Medical Encounter Database (CTR EMED), which has collected data on wounds, diseases, treatments, and patient outcomes from Iraq and Afghanistan since 2004. The data collected by the CTR EMED make up part of the Joint Theater Trauma Registry (JTTR), which also includes similar data collected by other military branches. A small army of medical coders, nurses, epidemiologists, and statisticians, overseen by an institutional review board, process these data. The data, in turn, help develop relevant patient streams for M&S analysis. A similar data collection effort is needed to make medical M&S for civilian responders possible. This certainly is not a new idea. In 2005, Fenig and Cone recommended the establishment of a national disaster-victim database (NDVD) capable of collecting real-time data on the injuries and illnesses seen during disasters. “A disaster-victim database will facilitate collection of comprehensive disaster data,” they wrote. “However, the data that the NDVD abstracts can only be as good as the data collected by personnel and individual facilities. Therefore, facilities should be encouraged to develop better standardization and collection methodologies” (Fenig & Cone, 2005). The following year, Heide also urged a comprehensive data collection effort during disasters: “Knowledge based on systematically collected data from field disaster research studies might help planners avoid common disaster management pitfalls, thereby improving disaster response planning” (Heide, 2006). Collecting Data

The logical center of gravity for this effort would appear, at first, to be the National Trauma Data Bank (NTDB), which has standardized injury reporting among state trauma registries. However, unless a disaster-related trauma is identified as such by an appropriate International Classification of Diseases, Ninth Revision (ICD-9) E code, it would not be identifiable as different from any other trauma. An attempt to use E codes to identify disaster-related traumas in the NTDB database during 2007 found only 244 records (Fantus & Hammond, 2007). This was nearly two years after Hurricane Katrina injured 2,018 persons in New Orleans alone. Many patient encounters likely were not properly recorded due to heavy patient volume (Willams et al., 2005). Even if all incidences of disaster-related trauma were recorded in the NTDB with the proper E codes, they would still tell only part of the story. The greater part of a medical disaster response is providing primary care for illnesses that may or may not be related to the disaster itself. The Centers for Disease Control and Prevention (CDC) estimates the number of persons seeking treatment for illnesses after Hurricane Katrina was 4,169, more than twice the number of those suffering traumatic injuries. An additional 1,321 patients seen after the hurricane required only medication refills or follow-up care (Willams et al., 2005), yet even those patients placed a logistical burden on the responding treatment facilities. Each type of patient seen by responders, from the response phase of a disaster through the recovery phase, must be considered when modeling medical requirements for such events. In other words, the data collection effort must be patient-centric, not logistics-centric. Counting the number of saline bags used in a disaster response shows only what was used, not why it was used. More important is being able to identify what conditions patients presented with, such as hemorrhagic shock or dehydration, along with their ages and co-morbidities, and in what numbers. In addition to patient presentations of disease and illness, a properly configured and maintained database allows the determination of not only how much IV fluid should be carried, but also what fluid types (crystalloids vs. colloids), what size catheters, what type of IV administration sets, and even whether other fluid resuscitation methods, such as oral rehydration salts, should be considered. The most likely sources for these kinds of data in the United States are the medical teams operated by the National Disaster Medical System (NDMS) and other medical disaster response units. During the response to Hurricane Katrina, the CDC launched a well-organized data collection effort focused on the NDMS and military medical units that responded to the disaster. Data collection was accomplished using a standardized Injury and Illness Report form to be completed by caregivers for each patient at the time care was given. This Injury and Illness Report form, however, was heavily weighted to the collection of disease type and occurrence. A revision of the form was made to collect more data on injury type and occurrence, but not on patient treatment (Wolkin & Noe, 2007). A few additional changes in this form, to include treatment given to patients as well as the anatomical location of injuries, would give greater visibility to the full range of patient presentations and aid in the statistical analysis of the patients' treatment.

NHRC's battlefield data collection efforts were maximized by combining the elements of its data collection form with the patient care report (PCR) providers are required to fill out. This combination of data form and PCR is a two-page, self-duplicating form that provides spaces for injury/disease type(s), mechanism of injury, anatomical locations, treatment record, and even type of body armor worn, if any. The attending provider fills out the form only once, which saves time. When completed, one page stays with the patient's medical record and the second is sent to NHRC for processing (Galarneau et al., 2004). Analysis of this data by NHRC researchers has resulted in numerous epidemiological studies on combat injuries, such as trauma brain injury and post trauma stress disorder, and deployment diseases. Another advantage of such data collection and analysis is the development of "patient streams" used in modeling to simulate various combat scenarios or deployment environments. Modeling Process

For several years, military medical modeling used 401 patient conditions (PCs) created by the Defense Medical Material Program Office (DMMPO) to represent typical combat and non-battle injuries and diseases encountered in the deployed field environment. These PCs were assigned statistical probabilities of occurrence, identified from patient encounter data in NHRC's CTR EMED and the JTTR mentioned earlier. PC probabilities vary according to deployed scenarios (i.e., large-scale conflicts, stability and support operations, counterinsurgency warfare, special operations) and geographic regions (desert, jungle, mountain, urban). Casualty-projection programs use these probabilities to develop patient streams used in the modeling process. These DMMPO PCs are now in the process of being replaced by ICD-9 codes. Like many other military medical modeling programs, NHRC's modeling process used the DMMPO PCs (and now ICD-9 codes) in its modeling method. That process links clinical tasks to each PC for each level of care (i.e., corpsman or medic, forward aid station, surgical facility) as well as the functional areas within those levels of care. The medical supplies and quantities required for completion of each clinical task are then identified and mapped to the appropriate task. The modeling process also identifies the number of patients expected to receive a clinical task, since not all patients will receive the same treatment. These clinical "task profiles" are built with input from the appropriate providers to ensure the model simulates how they work in a real-world field environment. Figure 1 provides an abbreviated representation of the NHRC supply modeling process. In this example, PC 005, a head injury, is treated in the triage area of a battlefield surgical facility. The task profile shows the clinical tasks likely to be performed on this patient type in that functional area, and the percentage of those patients expected to receive each task. The Equipment/Supplies column identifies the items needed to intubate a patient. Not shown in this figure are additional data fields used to calculate supply quantities. These fields include the supply amounts needed to complete the task, how often the task will be repeated in the first 24 hours of treatment, how often the task will be repeated in each subsequent 24-hour period, the time each task requires for completion, and the average length of stay at that level of care. This model is the underlying engine that runs NHRC's M&S programs. It is important that patient-driven models like NHRC's reflect how the various medical responders work in the field with the equipment and supplies they carry. Battlefield health care is divided into four levels of care, also known as roles. First is far-forward emergency care, which includes the combat medic or corpsman at the point of injury, and the forward aid station, staffed by a physician's assistant or general medical officer and a few enlisted medics. Next is resuscitative care, which includes Advanced Trauma Life Support, and life- and limb-saving "damage-control" surgery, but very limited holding capability. This is followed by definitive care, large, complex field hospitals where damage-control surgeries are completed, and moderately wounded soldiers can recover in ward beds before returning to duty. The final battlefield role is en route care, which provides ground and air transportation of freshly wounded soldiers from the battlefield to an MTF, and postsurgical patients from the operating room to the next highest level of care. Military medical M&S programs must reproduce not only the treatment patients receive at each of these levels of care, but also how each individual service branch operates in those roles. Similarly, disaster medical M&S programs need to account for the individual skill sets of civilian providers and civilian clinical levels of care. The clinical capabilities of paramedics in the field are far less than those of a physician in a hospital setting. The capabilities of a disaster field hospital will also be less than those found in a hospital ER, just as the ER capabilities will be less than those found in a trauma center. All of these factors must be taken into consideration when modeling the impact of disasters on medical care.

Advantages of Modeling

The accompanying sidebar explains in detail the extent of NHRC's military medical modeling efforts. Similar medical M&S capabilities could provide civilian planners with the capability to test hospital surge operations or hospital diversion strategies during disasters. For instance, when examining hospital surge capacity, planners typically count the number of staffed beds a hospital could open up to receive disaster victims. Planners, however, do not have good visibility on such things as critical equipment and supplies, patient movement, or provider availability (DeLia & Wood, 2008; Embrey, Clerman, Gentilman, Cecere, & Klenke, 2010). It is usually assumed, for example, that hospitals will have enough personnel to care for the patients in those extra beds. But there is evidence that this may not be the case. Many part-time hospital workers are employed by multiple hospitals or clinics, and those hospitals count on those workers to show up at their facility in the event of a disaster. Furthermore, a recentsurvey of hospital workers indicated up to a third would be unwilling to report for work during a severe influenza pandemic (Balicer et al., 2010). A civilian medical M&S program similar to NHRC's Tactical Medical Logistics Planning Tool (see sidebar) could allow planners to test hospital surge capacity assumptions with varying staffing levels.

Since the 9/11 attacks, several states have purchased large, deployable field hospitals for use during disasters. Often the design, equipping, and staffing of these hospitals was accomplished largely by guesswork. With the proper medical M&S capabilities, state planners could test a variety of virtual field hospital configurations to find the best fit for their needs before spending tax dollars on tentage and equipment. Supply blocks could be customized for each functional area in the field hospitals based on each state's vulnerability and hazard assessments (i.e., likelihood of hurricane, tornado, earthquake, flood). Time-phased push packages could be developed and made ready to resupply the field hospitals on a just-in-time basis. Critical equipment and supply shortfalls can be identified, as well as personnel shortages. Logjams in patient flow can be identified and corrected before the field hospital ever deploys.
Conclusion

An article in a recent issue of Military Medicine suggested the military's expertise in medical contingency planning should be leveraged for community-based medical response planning (Embrey et al., 2010). As discussed here, military medical planners make great use of medical M&S to take the guesswork out of the process. M&S has helped those planners cope with the stresses caused by fighting two wars and a shortage of medical manpower. The success of military medical M&S is directly related to the concerted effort the military health care community has made in collecting injury and illness data, in real time, on the battlefield. Civilian medical disaster planners could learn from military medicine's data collection and M&S efforts. To take full advantage of medical M&S, however, a rigorous long-term effort must be made to collect disaster response patient care data during the event. The collected data must include the type and number of injuries and illnesses seen by responders, including anatomical locations when appropriate and the treatment provided. Once collected, the data must be centralized so they can be coded and made available to researchers. As with military expeditionary medicine, empirically based M&S can help civilian medical disaster planners prepare for the infrequent but "predictable surprise." A Short History of Navy Medical Modeling and Simulation

U.S. Marine Corps doctrine calls for maintaining a small logistical footprint to allow for a rapid response from the sea to emerging contingencies. As such, Marine medical treatment facilities (MTFs) have to be small, relatively lightweight, and quickly deployable. In the late 1990s, the Marine Corps turned to modeling and simulation (M&S) to analyze the size of its field MTFs. With the support of the Office of Naval Research, the Naval Health Research Center (NHRC) in San Diego, California, was tasked with developing an evidence-based modeling tool to perform that analysis. The result was the Estimating Supplies Program (ESP), a deterministic, computer-based, patient-driven model of clinical events that analyzes logistical requirements for specific battlefield scenarios. From the start, ESP was able to reduce the size of Marine Corps medical inventories by an average of 30% while increasing their treatment capabilities (Galarneau, Konoske, Emens-Hesslink, & Pang, 1998; U.S. Patent No. 7,707,042, 2010). ESP's underlying database of service-specific medical equipment and supplies, clinical tasks, treatment protocols, and models is housed in the Expeditionary Medical Knowledge Warehouse (EMedKW). Besides being used to trim existing Marine MTFs, NHRC's modeling process has been used to develop new battlefield treatment facilities. Among these is the Forward Resuscitative Surgical System, essentially a trauma center packed into three Humvees that was spotlighted by CNN's medical correspondent Dr. Sanjay Gupta during his coverage of the invasion of Iraq. Another battlefield development that was assisted by NHRC's modeling process is the Marine Corps' airborne casualty evacuation system, which has kept hundreds of wounded Marines and sailors alive as they were flown from the front line to the surgical hospital (Galarneau, Konoske, & Pang, 1999; Hill, Galarneau, Pang, & Konoske, 2004). In addition to ESP, EMedKW's database provides the foundation for several other NHRC M&S programs. The ReSupply Validation Program (RSVP) uses the ESP modeling process to develop time-phased medical resupply strategies, including push packages. RSVP is also used by the Marine Corps to develop its medical contingency file, a list required by the Pentagon every six months of the medical supplies each military branch would need in the event of a major contingency, such as a large–scale war. EMedKW also provides the underlying database for the Tactical Medical Logistics Planning Tool (TML+), a medical risk-assessment planning tool. The TML+ graphical user interface allows planners to create either a single treatment facility, such as a field hospital, or an entire network of MTFs and the transportation assets (aircraft, ambulances) needed to move patients between them.

Being stochastic rather than deterministic, TML+ uses multiple iterations of varying patient streams to identify logjams caused by shortages in equipment, consumables or transportation assets, shortfalls in personnel, and even increases in patient mortality due to delays in treatment. Planners can perform "what if" experiments to study the effects of increasing or reducing personnel, adding or subtracting treatment beds, or mixing ground and air evacuation assets. (Olson, Bohannan, Peel, Jeschonek, & Leap, 2007). TML+ has the ability to simulate routine field medical operations, such as sick call, or contingency medical operations for large-scale combat assaults, peacekeeping and stability operations, and unexpected mass casualty events. Originally conceived as a battlefield–planning tool, TML+ also has been used to provide course-of-action analysis, manpower studies, even the viability of using unmanned aerial vehicles for casualty evacuation. Powering NHRC's modeling effort is the statistical analysis of combat injuries and diseases. Originally, this focused on data from previous wars such as World War II, Korea, Vietnam, and Operation Desert Storm. In 2004, NHRC launched the Navy-Marine Corps Combat Trauma Registry, a long-term data collection effort tracking patient care of sailors and Marines from as far forward as frontline battalion aid stations through the entire continuum of military medical care, including definitive and rehabilitative care back in the United States (Galarneau et al., 2004). Because the registry collects data on disease and non-battle injuries as well as combat casualties, it now called the CTR Expeditionary Medical Encounter Database. With two wars straining our military's personnel and funding, M&S has become an important tool in all fields of military planning in all branches of the service. Besides the Marine Corps, today EMedKW houses ESP medical models for both Navy surface-fleet and ground-combat assets, as well as the U.S. Air Force. Those models represent the entire battlefield continuum of care, from point of injury to definitive treatment in the USAF's Expeditionary Medical Support System field hospitals. Special Operations units are also represented, as are terrorism-response teams such as the Marine Corps' Chemical Biological Incident Response Force, which can respond to terrorist attacks within the United States and abroad (Hill, Galarneau, Pang, & Konoske, 2003; Hill, Konoske, Pang, & Galarneau, 2006). EMedKW is an all-hazards approach and models noncombat injuries, disease, field preventive medicine, and environmental injuries, as well as combat injuries. With an increased national focus on military response to disasters and humanitarian crises, NHRC researchers are currently studying patient presentations from such disasters as the 2004 tsunami, the 2005 Sumatra earthquake, and the devastating 2010 earthquake in Haiti. Analysis of those data will eventually lead to modeling tools to aid medical planners in preparing for HA/DR deployments.

Author Bio

Martin Hill, a research analyst with Naval Health Research Center in San Diego, California, specializes in military expeditionary medical capabilities. A 16-year veteran of the U.S. Coast Guard and U.S. Navy Reserve, he currently serves as a Medical Service Corps officer in the California State Military Reserve, where he trains Army National Guard combat medics. A National Registry Emergency Medical Technician, Hill also served six years as a medical specialist and tactical medic with the San Diego County Sheriff's Search and Rescue Detail. In addition, he served on a federal Disaster Medical Assistance Team and with the San Diego Medical Reserve Corps, and is an American Red Cross instructor. Hill holds a Level III Certification in Homeland Security from the American Board for Certification in Homeland Security, and he is a qualified Military Emergency Management Specialist.
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Disaster Medicine: Using Modeling and Simulation to Determine Medical Requirements for Responding to Natural and Man-Made Disasters

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14. ABSTRACT

It has been suggested that civilian emergency managers should leverage the knowledge and expertise of military medical planners when preparing for medical disaster response. Like their civilian counterparts, military medical planners are faced with personnel shortages and restricted resources. Military medicine, therefore, uses medical modeling and simulation (M&S) to take the guesswork out of developing new field medical capabilities or to preplan deployments for any number of emergency contingencies in austere environments. Civilian disaster medical planners could learn from military medicine's M&S efforts. To take full advantage of medical M&S, however, civilian researchers must make a concerted, long-term effort to collect patient care data during disaster responses. The collected data must include the type and number of injuries and illnesses seen by responders, including anatomical locations when appropriate, and the treatment provided. Once collected, the data must be centralized so it can be coded and made available to medical analysts.

15. SUBJECT TERMS
modeling and simulation, disaster, planning, medical response

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